

THE PURPOSE AND APPLICATION OF ISO 21501-4

APPLICATION NOTE CC-117 (US)

Introduction

ISO 21501 is titled “*Determination of particle size distribution – Single particle light interaction methods*” and consists of 4 parts. *Part 4: Light scattering airborne particle counter for clean spaces* applies to handheld, portable and remote airborne particle counters used in cleanrooms. This standard was released in 2007, and, together with ISO 21501-2 and 21501-3, replaces ISO 13323-1:2000. The purpose of ISO 21501-4 is “to provide a calibration procedure and verification method for particle counters, so as to minimize the inaccuracy in the measurement result by a counter, as well as the differences in the results measured by different instruments.” ISO 21501-4 sets minimum performance standards for airborne particle counters and defined methods for calibration and verification of performance. While standards existed previously that covered these topics, none were as comprehensive as ISO 21501-4.

Scope of ISO 21501-4

Table 1 shows the parameters that are listed within ISO 21501-4 and the accompanying requirements. In addition, ISO 21501-4 requires that the calibration particles have a standard uncertainty of the mean particle size $\leq \pm 2.5\%$, defines the minimum information to be included in a test report, and the minimum parameters that should be calibrated at the calibration interval. The minimum information for each test report is listed in Table 2, and the minimum calibration parameters are listed in Table 3.

Table 1. Scope of ISO 21501-4

Parameter	Requirement
Size calibration	Calibrated using median voltage (or internal PHA channel) for each calibration particle with the peak of the distribution at least 2X the minimum noise level at the valley of the distribution
Verification of size setting	$\leq \pm 10\%$
Counting efficiency	(50 $\pm$ 20)% close to the minimum detectable particle size (100 $\pm$ 10)% for particles 1.5 to 2 times larger than the minimum detectable size

Parameter	Requirement
Size resolution	$\leq 15\%$ for particles at a size specified by the manufacturer
False count rate	To be determined in units of counts/m ³ at the minimum reported size range (note: there is no specification in the standard)
Maximum particle number concentration	To be specified by manufacturer at a coincidence rate $\leq 10\%$
Sampling flow rate	Standard uncertainty of volumetric flow rate $\leq \pm 5\%$
Sampling time	Standard uncertainty of sampling time duration $\leq \pm 1\%$
Response rate	Response rate of the particle counter shall be $\leq 0.5\%$
Calibration interval	Recommended calibration interval to be one year or less

Table 2. Minimum Required Test Report Information

Date of calibration
Calibration particle sizes
Flow rate
Size resolution (with particle size)
Counting efficiency
False count rate
Voltage limit or channel of internal pulse height analyzer

Table 3. Minimum Calibration Parameters

Size calibration
Size resolution
Counting efficiency
Sampling volume uncertainty (dependent on sample flow rate and sampling time uncertainty)

Size Calibration

ISO 21501-4 clearly defines a recommended method of calibrating particle size, along with minimum requirements for differentiation between measured particles and noise. Figure 1 shows a pulse height distribution from a particle counter suffering from high noise levels. While it is possible to see the peak of the distribution resulting from the calibration particles, noise levels are too high for reliable, repeatable measurements. Figure 2 shows data with an even higher noise level. The calibration particles are completely lost in the noise. Neither of these instruments meet the requirements of ISO 21501-4. Figure 3 shows a pulse height analysis that meets the ISO 21501-4 criteria, with the particle counts at the peak of the distribution being a minimum of 2 times the counts at the valley. This ensures that the instrument has an adequate signal-to-noise ratio for reliable, repeatable measurements. As Figure 4 shows, the median of the portion of the pulse height distribution that has values above the noise “valley” is used to determine the particle size calibration value.

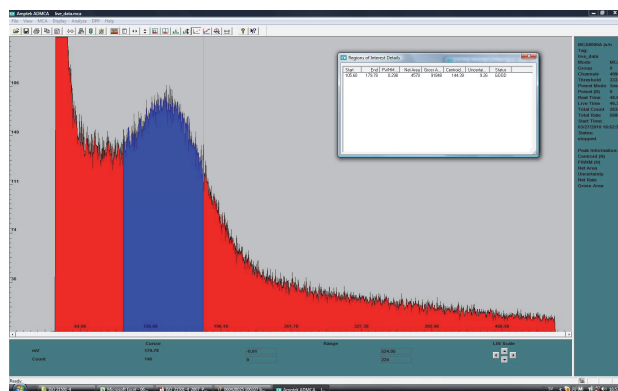


Figure 1. High noise pulse height distribution

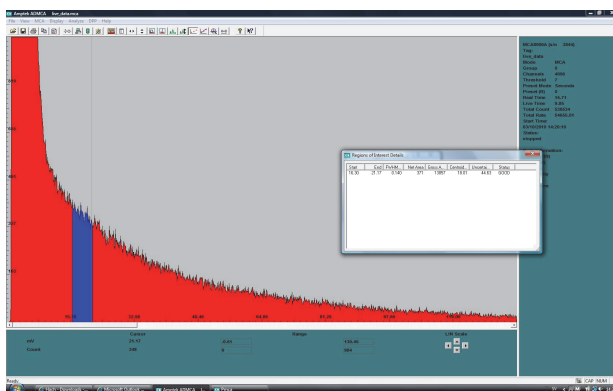


Figure 2. Very high noise level pulse height distribution

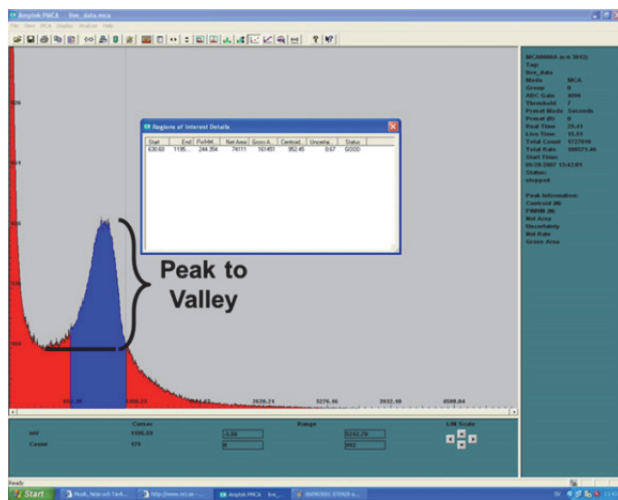


Figure 3. Acceptable noise level in pulse height distribution

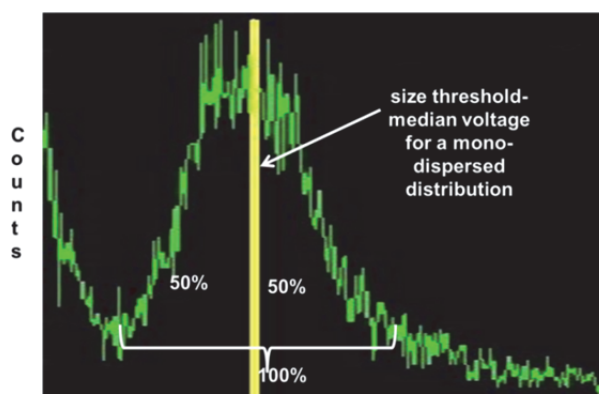


Figure 4. Determination of particle size calibration

Verification of Size Setting

The calibration data generated in the size calibration is used by the instrument manufacturers to determine a calibration curve. This curve is then used to determine the desired channel settings (Figure 5). For the verification of size setting, ISO 21501-4 states that at least 3 kinds of calibration particles that span most of the instruments size range are used to determine the instrument's response voltages (or pulse height analyzer channel). This corresponding particle size is then determined using the instrument's calibration curve. ISO 21501-4 requires that the error in particle size be $\leq \pm 10\%$.

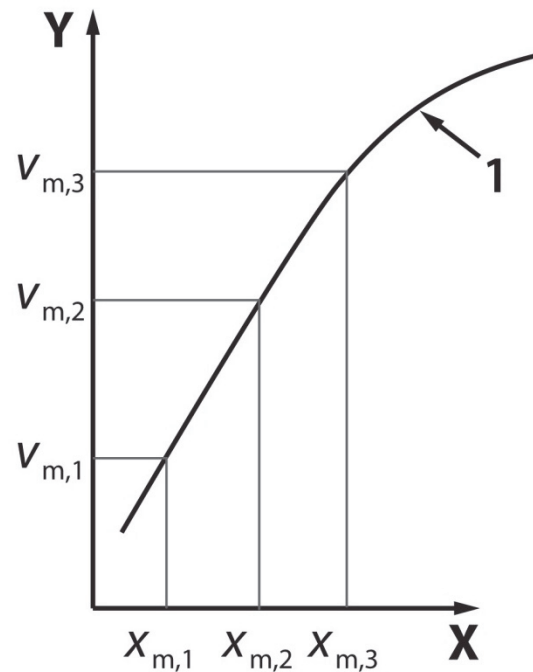


Figure 5. Particle counter calibration curve

Counting Efficiency

Counting efficiency is to be tested at two particles sizes. The first size must be close to the minimum detectable particle size. The second size is to be 1.5 to 2 times larger than the minimum detectable particle size. To measure the counting efficiency, the particle number concentration of the instrument being measured is compared to a reference instrument (Figure 6). ISO 21501-4 requires that the counting efficiency near the minimum detectable size be $(50 \pm 20)\%$ and the counting efficiency at the larger particle size be $(100 \pm 10)\%$.

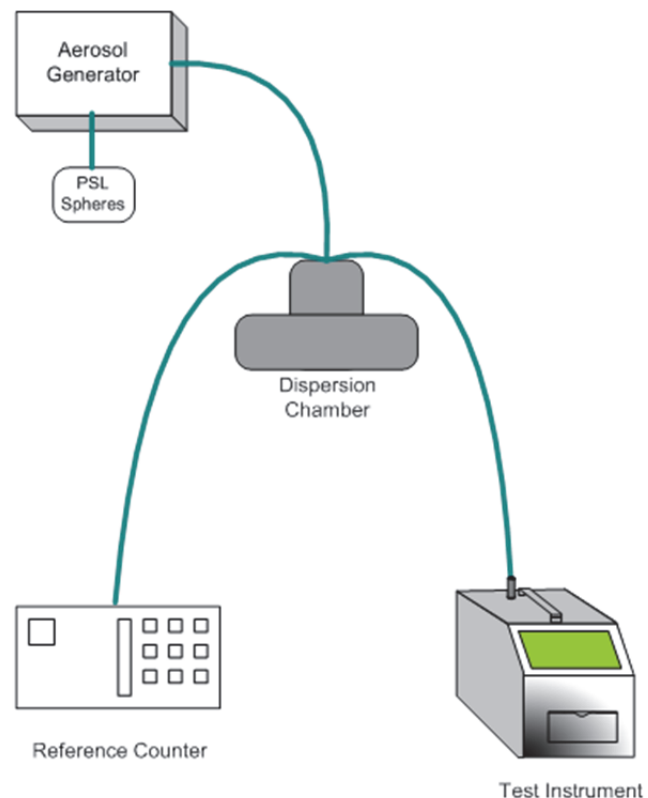


Figure 6. Measurement of counting efficiency

Size Resolution

Size resolution is the ability of the instrument to differentiate between similarly sized particles. It is defined as the standard deviation of the distribution measured with the pulse height analyzer (corrected for the standard deviation of the calibration particles) divided by the size of the calibration particles (Equation 1). The standard deviation of the pulse height analysis is determined per Figure 7. The calibration curve is used to determine the particle sizes corresponding to the upper and lower voltage limits of the 61% point of the size distribution. ISO 21501-4 required that size resolution be $\leq 15\%$ for particles at a size specified by the manufacturer.

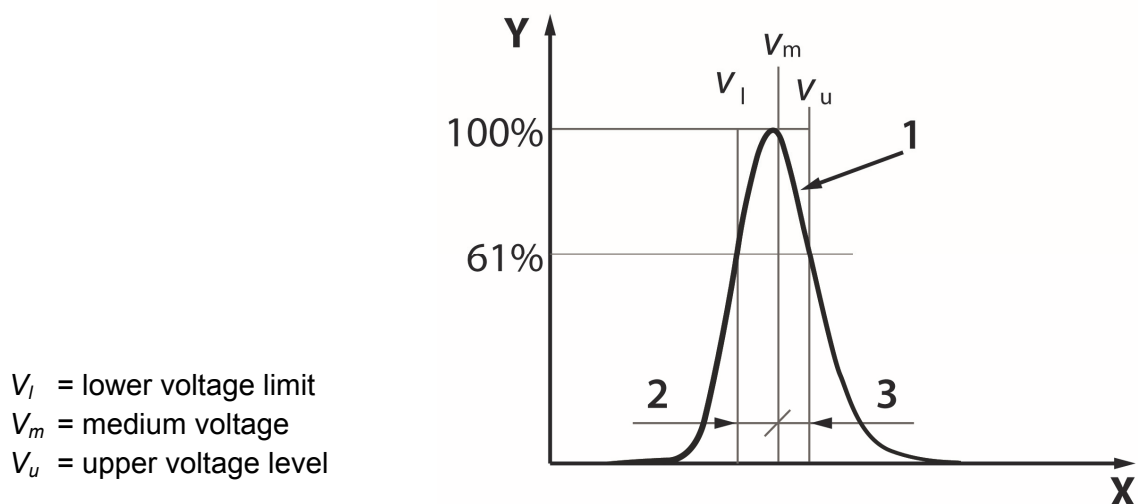


Figure 7. Determination of size resolution

$$R(\%) = \frac{\sqrt{\sigma^2 - \sigma_p^2}}{x_p} \times 100\%$$

Equation 1. Calculation of size resolution

False Count Rate

The false count rate is the measured particle concentration, expressed in particles/m³, when the particle counter is set to the minimum detectable size and sampling particle-free air. The data is to be expressed with a 95% upper confidence limit using Poisson statistics. ISO 21501-4 does not specify a limit for the false count rate, but only that it be measured and recorded. Some particle count manufacturers, including TSI, use the limit for false count rate established by JIS B 9921:1997, which is ≤ 1 particle in 5 minutes at 95% confidence (which means 1 particle or less in 15 minutes). If a 1 CFM instrument (28.3 L/min) measured 1 particle in 15 minutes, the total volume sampled would be 424.5 l (28.3 L/min $\times$ 15 minutes). Poisson statistics (Table D.1 in ISO 21501-4) shows the 95% upper confidence limit for 1 count as 4.7. Therefore, the false count rate would be shown as 11 particles/m³ (4.7/0.4245).

Maximum Particle Concentration

Coincidence occurs when more than one particle is passing through the instruments sensing zone and are detected as a single, larger particle. Coincidence can be calculated from the instruments flow rate and the time required for a particle to pass through the sensing zone and resulting electronic signal processed. The maximum particle concentration is specified by the manufacturer, and is the point at which coincidence loss will be $\leq 10\%$.

Sampling Flow Rate and Sampling Time (Sample Volume)

Because particle counters measure particle concentration, the final measurement will be affected by errors in the sample volume. The accuracy of the sample volume is a function of errors in both the sampling flow rate and the sampling time. ISO 21501-4 specifies accuracies for both. The maximum allowable error in sampling time is $\pm 1\%$. The maximum allowable error for sampling flow rate is $\pm 5\%$. The sampling flow rate must be calibrated with a flow meter that has a low pressure drop so as not to affect the flow through the instrument. In addition, the flow should be reported as a volumetric flow rate.

Response Rate

The response rate shows how fast the particle counter can respond to a step change in particle concentration. To measure response rate, the particle counter is first challenged with PSL particles near the maximum rated particle concentration, with the PSL particle size near the lower detection limit for 10 minutes. The particle concentration is then measured for a duration of 60 seconds or less. At the end of the sample, the sample is changed to clean air. After 10 seconds, the particle concentration is measured again. The ratio of the two measured concentrations is the response rate, and must be $\leq 0.5\%$.

Summary

Prior to ISO 21501-4, no international standards existed that required all critical parameters on airborne particle counters to be tested and meet specific performance requirements. ISO 21501-4 sets a minimum performance and calibration standard that ensures accurate measurements and reduces variability between instruments. The implementation of this standard forced improvements in calibration systems and, often, improvements in airborne particle counter design and performance. Many older instruments are not capable of meeting the performance requirements of ISO 21501-4.

References

ISO 21501-4:2007 *Determination of particle size distribution – Single particle light interaction methods – Part 4: Light scattering airborne particle counter for clean spaces*



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